Evaluation of Spillway Adequacy

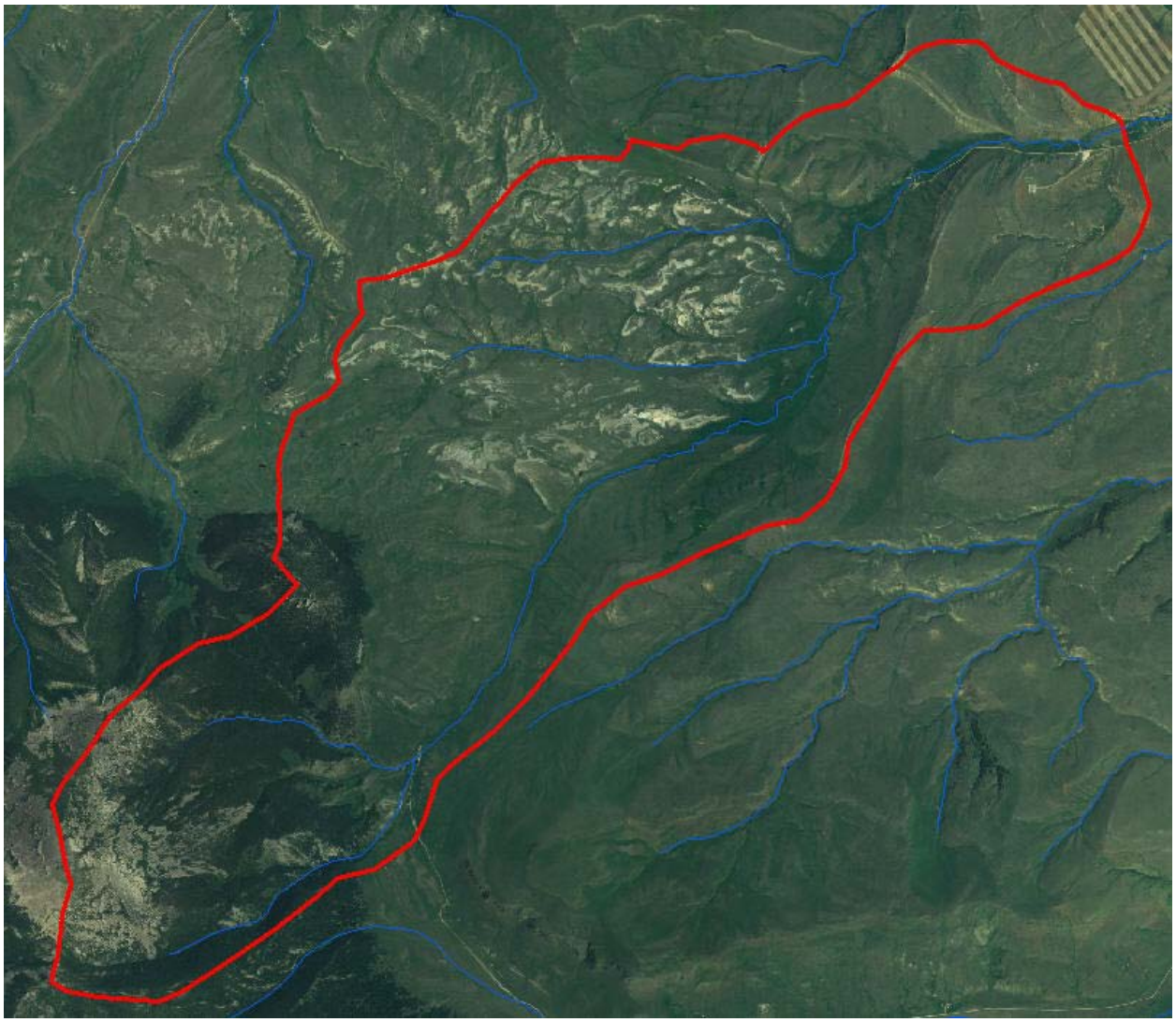
Example Number 1

Fish Creek Dam

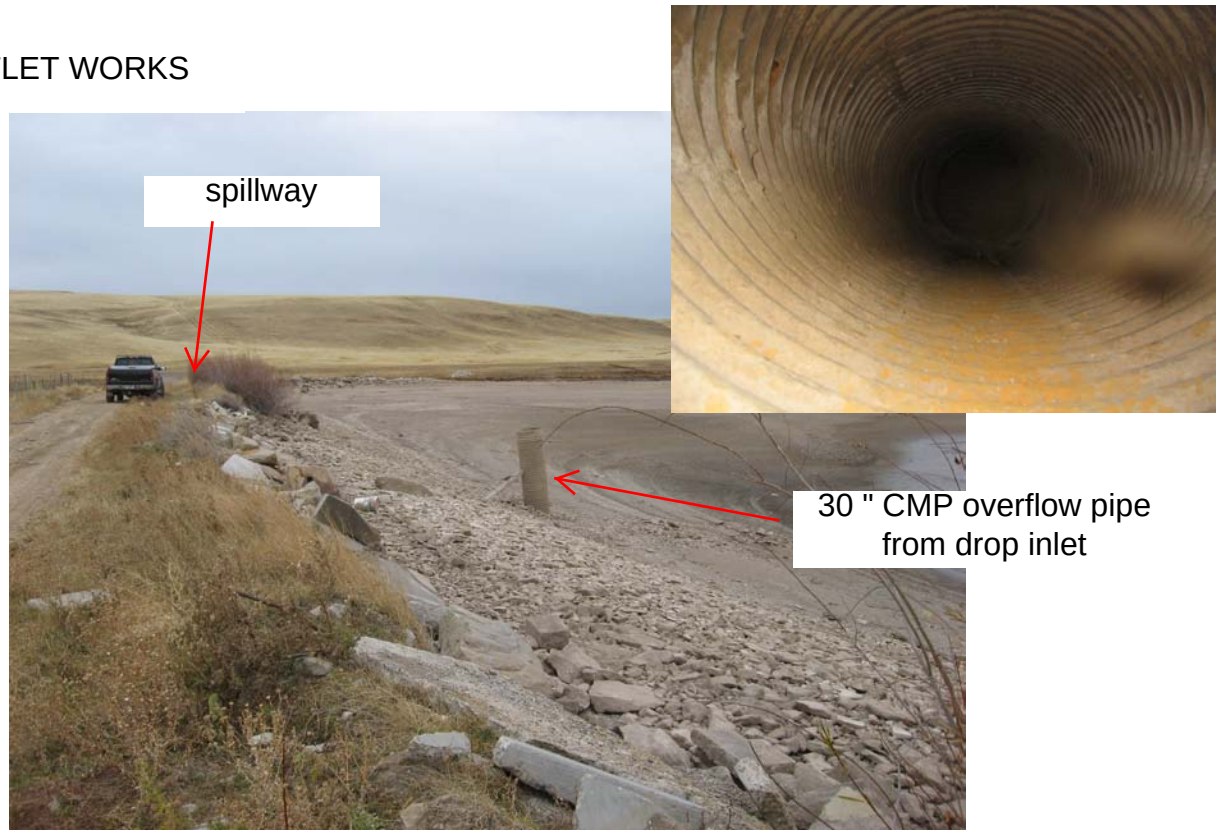
LOL 0 to 5: Fish Creek Dam

Purpose of Analysis: To determine if dam is compliant with MT spillway design standards

Dam / Reservoir Information:
Normal Capacity (measured it principal spillway drop inlet): 134.2 ac ft
Max Capacity (measured to dam crest): 148 ac ft
Elevation auxiliary spillway: 4434.1 ft
Elevation Dam crest: 4437.5 ft
Outlet Pipe invert elevation: 4409 ft
Elevation of top of drop inlet: 4436.3 ft
Freeboard: 3.4 feet (Distance from top of dam to auxiliary spillway)
Surface area of reservoir: 12.3 acres
Outlet works: CMP drop inlet; 30 inch CMP overflow conduit; 24” low level outlet
Spillway: earthen, 65 feet wide, grass lined, with low earthen berm at crest
Drainage area: 15.8 sq miles; 10.4 % of basin > 6000 feet

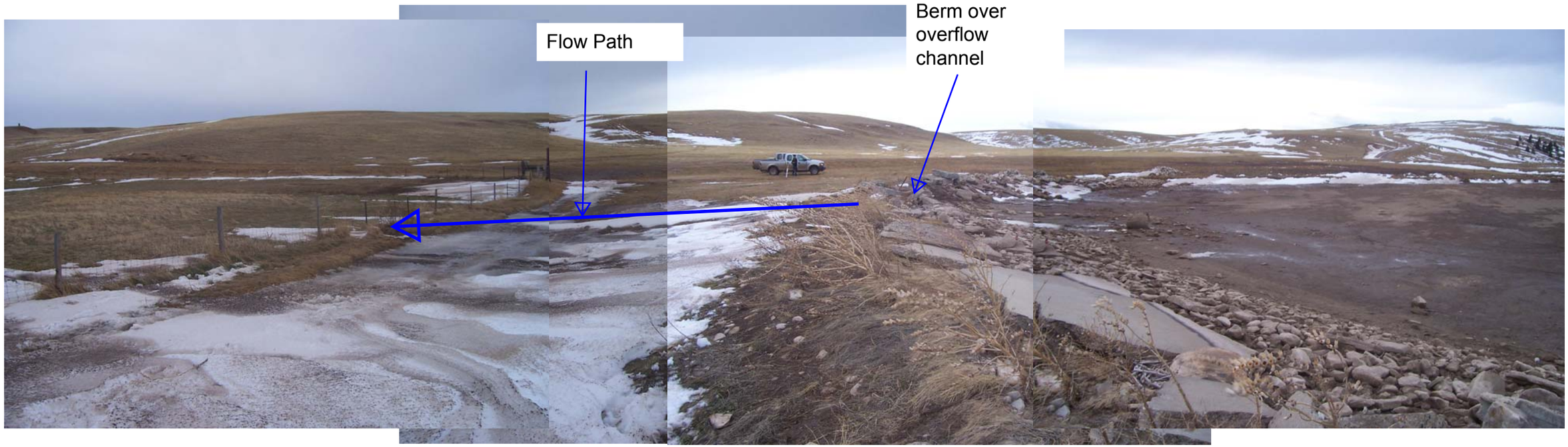


OUTLET WORKS

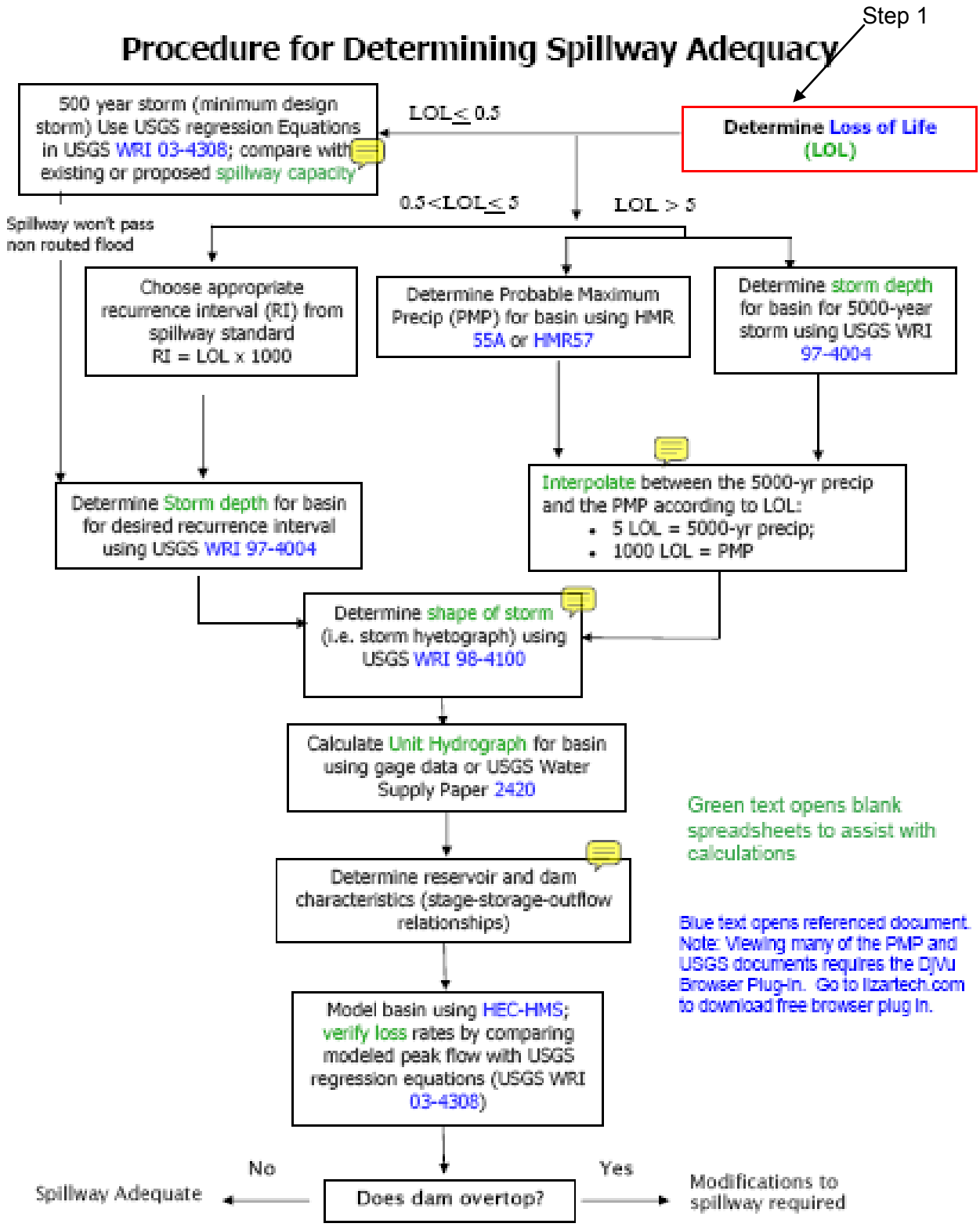


Looking up drainage area

DAM

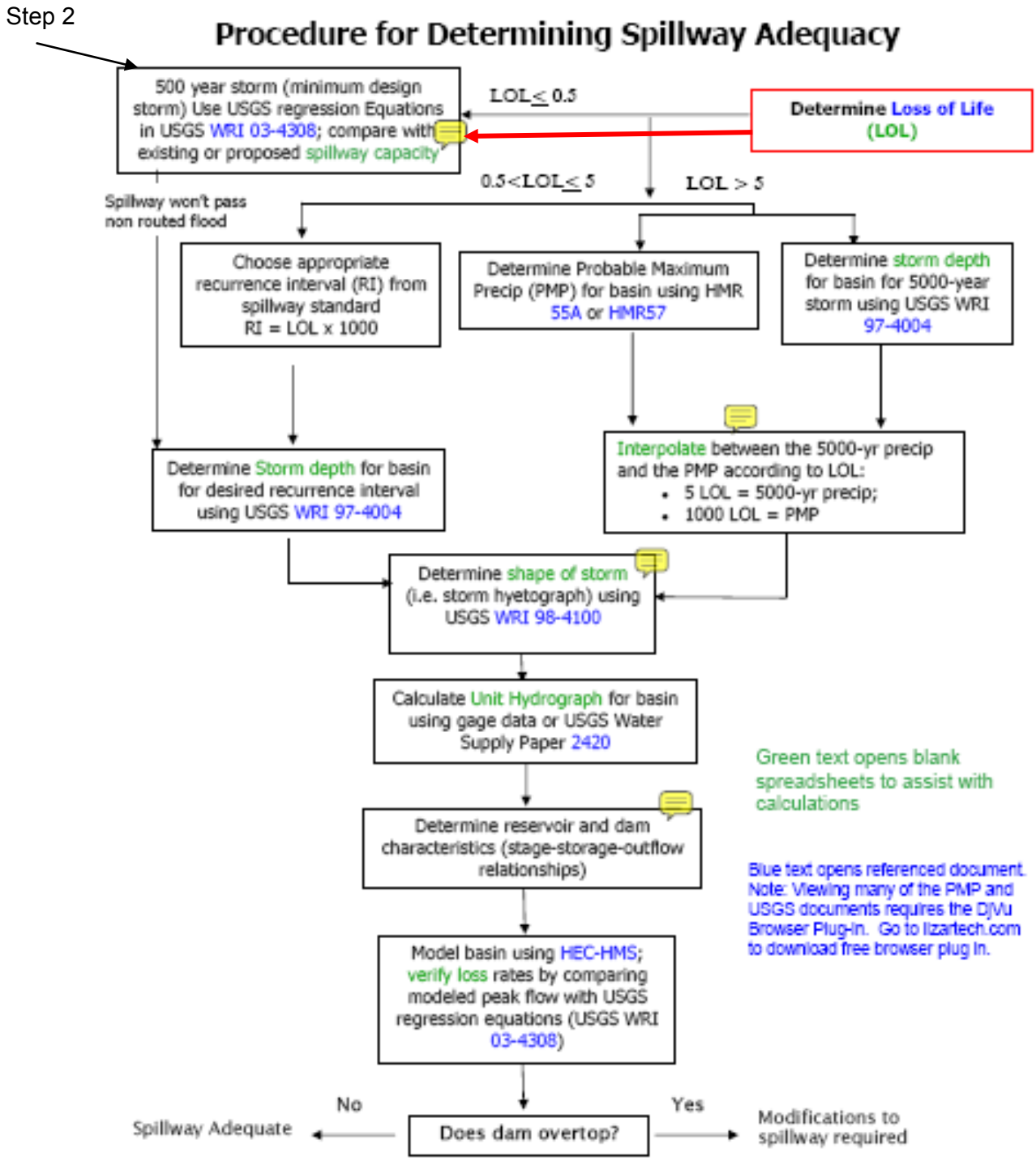

Flow Path
Berm over
overflow
channel

Step 1 – Determine Loss of Life (LOL) using methods described in Technical Note 2



Loss of life is determined by routing a dam failure downstream with starting water surface at top of dam, using methods described in TN 2. For the Fish Creek Dam, the loss of life was determined to be 0.27. Since the loss of life is less than 0.5, the minimum design storm of 500 years is the requirement.

Step 2 – Check to see if spillway passes non routed minimum design storm.



First, calculate 500 year storm using USGS regression Equations

Summary of Estimation Parameters Selected:

Name for this estimation: **Default**
Region: **Upper Yellowstone**
Estimation method: **Basin and Climatic Characteristics Only**
Drainage area in square miles: 15.8
Percent basin above 6,000 feet: 10.4

Flood Discharge Estimation:

(In the Flood Discharge table, RI is the Recurrence Interval, in years; STD ERR is the Standard Error; and 90% PRED. INTERVAL is the 90% Prediction Interval, in cubic feet per second)

```
 METHOD: Regression on basin characteristics
 Flood frequency estimates for
 Default
Upper Yellowstone-Central Mountain Region: A =     15.80 E6 =    10.
 RI        DISCHARGE  STD ERR OF              90% PRED. INTERVAL
             (cfs)      PREDICTION(%)
     2         74.        93.4              19.8              274.
     5        174.        71.5              60.0              507.
    10        274.        62.3             106.0              709.
    25        436.        56.1             183.1             1040.
    50        583.        54.8             249.1             1360.
   100        751.        55.6             317.3             1780.
   200        945.        58.2             385.5             2320.
   500       1250.        63.8             472.6             3290.
```

Simplified methods can be used to determine if the spillway passes the unrouted 500 year storm. One simplified method is the broad crested weir equations. Some assumptions may need to be made about spillway geometry

B (width)	C (range 2.6 to 3.1)	Q 500	H1 (approach depth above weir crest)	Freeboard	okay? (is approach depth less than freeboard)
65	2.8	1250	3.61	3.4	no

Basic Weir Equation

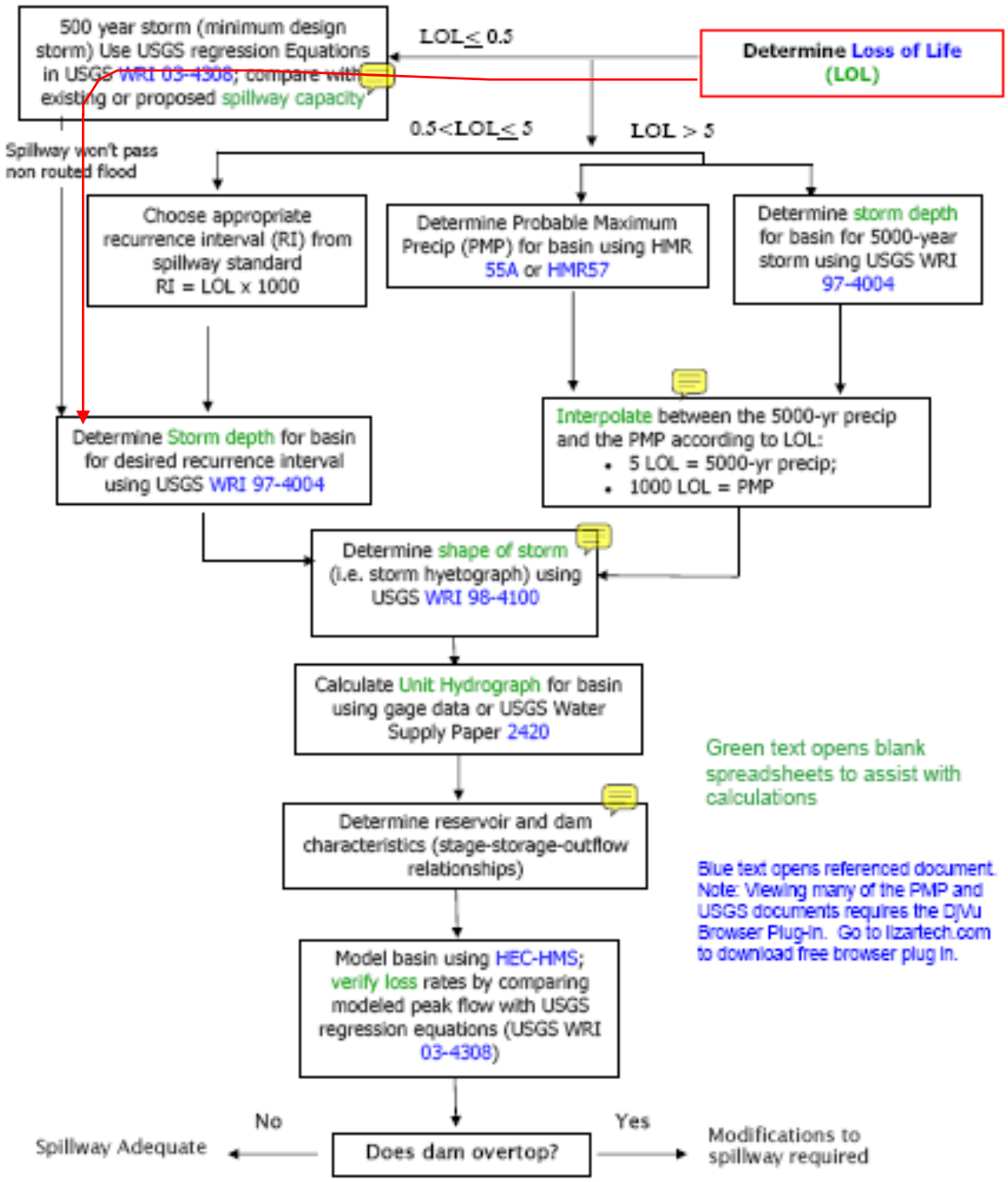
$$Q = CLH^{3/2}$$

Where:

Q is discharge in ft^3/s
L is Length of the Weir Crest (ft)
H is the head of water above the crest measured at some distance upstream (ft)
C is a discharge coefficient for the weir.

Step 3– Since spillway doesn't pass unrouted 500 year peak flow, it will be necessary to route storm. First, the storm depth must be determined.

Procedure for Determining Spillway Adequacy



Note: The assumption that recurrence interval of the storm is equivalent to recurrence interval of the runoff is commonly made. However, a storm depth having a given recurrence interval can produce runoff having a wide range in recurrence intervals depending upon the location, uniformity and temporal characteristics of the storm and hydrologic conditions in the basin.

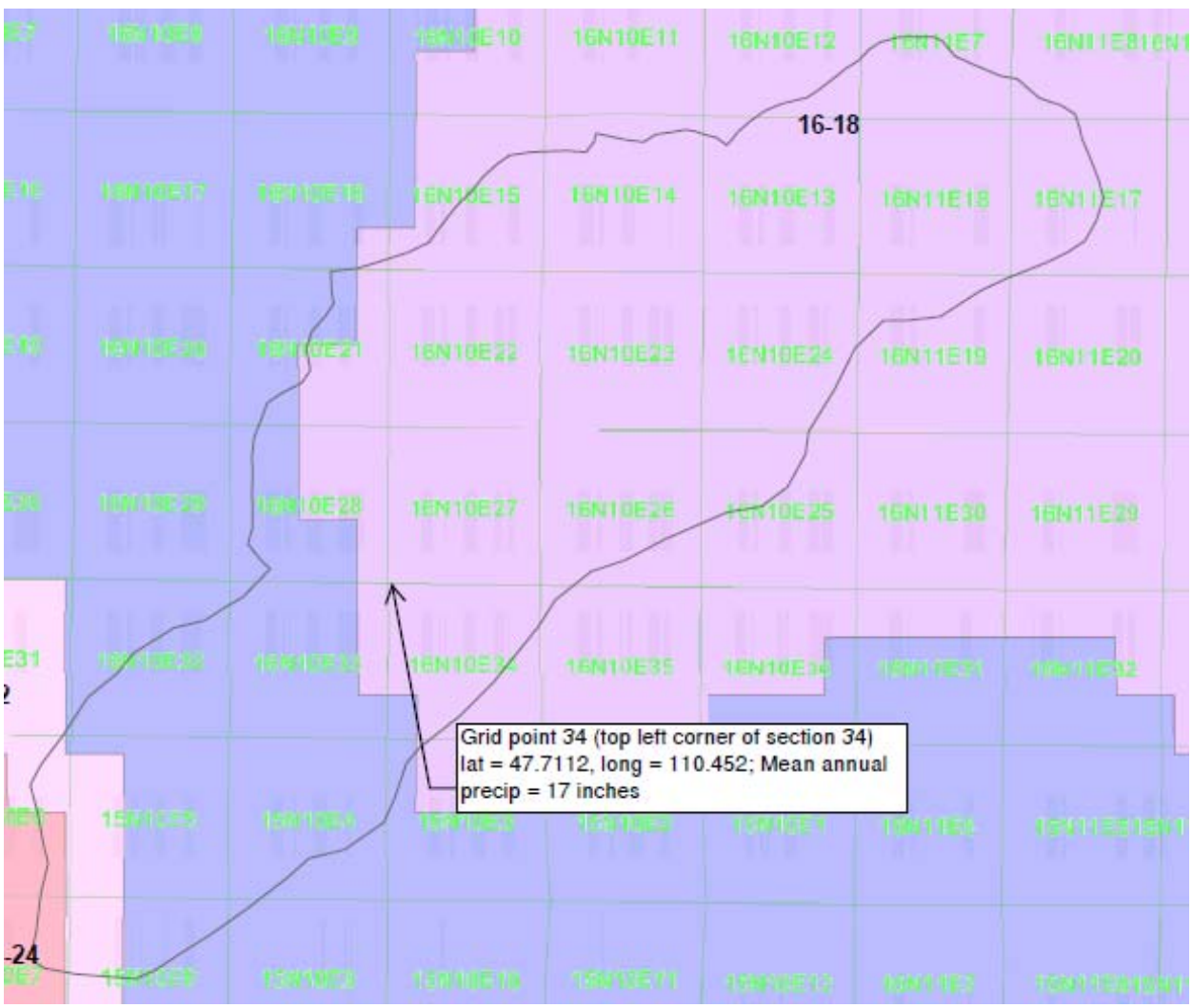
Using WRI 97-4004, calculate the 24 hour storm depth. Input includes Lat, long and mean annual precipitation. Fish Creek is located in region 2

Table 11. Regression equations for estimation of mean storm depth for indicated duration in Montana

[Regression equation: *Pmax*t, storm depth in inches, with t indicating duration in hours; *LAT*, site latitude, in decimal degrees minus 40; *LONG*, site longitude, in decimal degrees minus 100; and *MAP*, mean annual precipitation, in inches, as determined from State maps prepared from digital data from Oregon State University Climate Center (pl. 2)]

Region		Equation	Standard error, inches	Coefficient of determination, R^2
1	$Pmax2$ =	$0.44 + (0.0027 \times MAP)$	0.05	0.10
	$Pmax6$ =	$0.60 + (0.0067 \times MAP)$	0.07	0.31
	$Pmax24$ =	$1.0 + (0.078 \times LAT) - (0.059 \times LONG) + (0.025 \times MAP)$	0.16	0.80
2	$Pmax2$ =	$0.69 + (0.034 \times LAT) - (0.029 \times LONG)$	0.09	0.16
	$Pmax6$ =	$0.75 + (0.087 \times LAT) - (0.041 \times LONG)$	0.12	0.30
	$Pmax24$ =	$1.4 + (0.18 \times LAT) - (0.13 \times LONG) + (0.019 \times MAP)$	0.27	0.52
3	$Pmax2$ =	$0.70 + (0.031 \times LAT) - (0.040 \times LONG) + (0.0087 \times MAP)$	0.08	0.62
	$Pmax6$ =	$0.85 + (0.031 \times LAT) - (0.038 \times LONG) + (0.015 \times MAP)$	0.08	0.59
	$Pmax24$ =	$0.62 + (0.039 \times LAT) - (0.016 \times LONG) + (0.058 \times MAP)$	0.16	0.49

The drainage area must be placed over a uniform grid. The PLSS makes a nice grid to use. Pick the lat, long and mean annual precipitation off of the top left corner of each section



Calculate the 24 hour storm depth for each grid point using equations in table 11. Apply the dimensionless depth for the 500 year recurrence interval (Figure 13, below) to get storm depth. Apply an area adjustment factor using Figure 19.

500 year precipitation for 24 hour storm Source WRI 97-4004

grid point	region	Lat	Long	MAP	P24	Dim.depth	Depth (in)
					table 11	Figure 13	
8	2	7.084	10.495	21	1.71	3.41	5.83
5	2	7.097	10.495	19	1.67	3.41	5.71
9	2	7.083	10.473	19	1.67	3.41	5.71
4	2	7.098	10.473	19	1.68	3.41	5.72
3	2	7.098	10.453	19	1.68	3.41	5.73
34	2	7.112	10.452	17	1.64	3.41	5.61
27	2	7.126	10.453	17	1.65	3.41	5.62
22	2	7.14	10.45	17	1.65	3.41	5.63
35	2	7.11	10.43	17	1.65	3.41	5.62
26	2	7.126	10.43	17	1.65	3.41	5.63
23	2	7.141	10.433	17	1.65	3.41	5.63
25	2	7.126	10.41	17	1.65	3.41	5.63
24	2	7.141	10.409	17	1.66	3.41	5.64
17	2	7.14	10.387	17	1.66	3.41	5.65
18	2	7.16	10.39	17	1.66	3.41	5.66

Avg at site storm depth	5.67	
Area adjustment factor	0.98	Figure 19
Basin average depth	**5.55**	

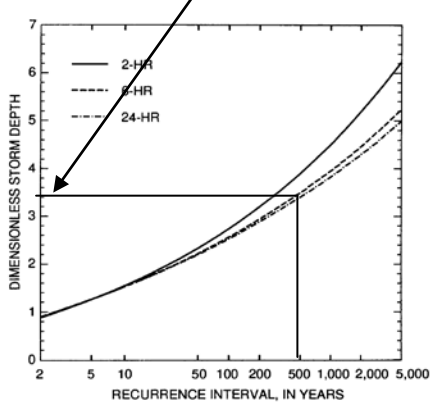


Figure 13. Regional frequency curves for dimensionless annual storm depths for Region 2, Montana.

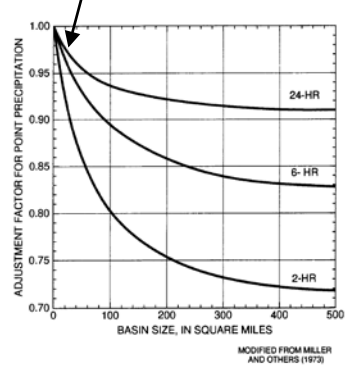
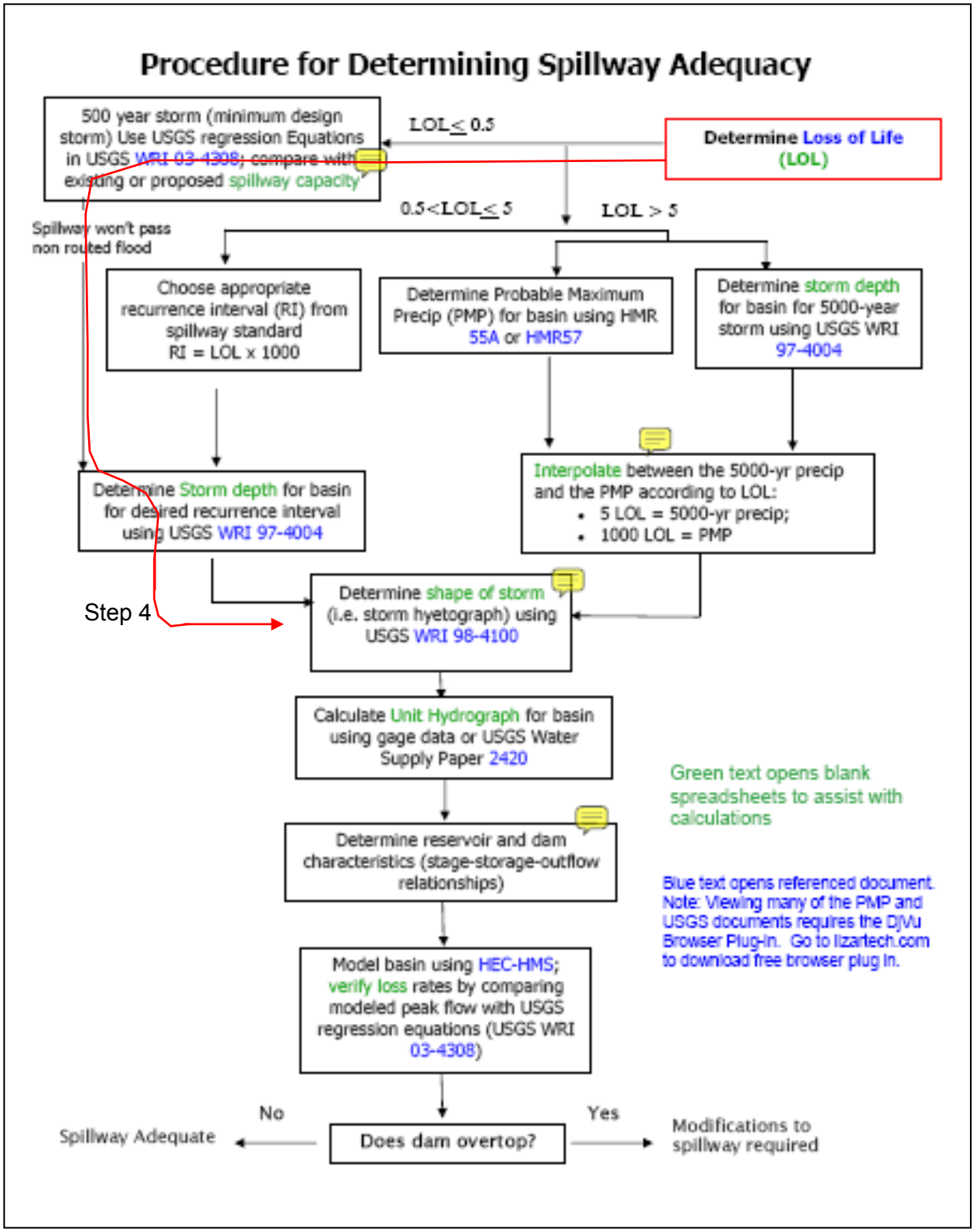


Figure 19. Depth-area adjustment curves for Montana.

The resulting basin average non areal adjusted storm depth is 5.67 inches

Step 4– Determine the temporal characteristics of the storm (storm hyetograph), using WRI 98-4100



1. Determine exceedance probability values for each duration for appropriate region. For this example, Table 14 is used. A 50% exceedance probability is recommended. Plug those values into the spreadsheet.
2. Determine the appropriate depth area adjustment using Figure 17. Note – do not double account for depth area adjustment if previously incorporated in extreme storm calculations.
3. Use spreadsheet to calculate storm depth per 1 hour period. These are your hyetograph values.

Table 14 for region 2

24-hour independent duration 6-hour kernel duration

Dependent duration (hours)	Exceedance probability								
	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
1	0.070	0.094	0.109	0.115	0.121	0.127	0.134	0.143	0.156
2	.120	.144	.163	.188	.197	.207	.218	.232	.252
3	.170	.193	.214	.232	.250	.276	.290	.308	.334
6	.320	.344	.365	.384	.403	.424	.447	.476	.519
9	.470	.495	.516	.536	.556	.577	.601	.631	.675
12	.594	.618	.639	.658	.677	.698	.720	.749	.792
18	.822	.835	.846	.856	.866	.877	.890	.905	.928
24	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
36	1.172	1.154	1.139	1.125	1.111	1.096	1.080	1.064	1.048
48	1.235	1.218	1.203	1.190	1.177	1.162	1.146	1.126	1.096
60	1.300	1.277	1.257	1.239	1.220	1.200	1.178	1.150	1.108
72	1.326	1.300	1.278	1.258	1.238	1.215	1.191	1.160	1.114

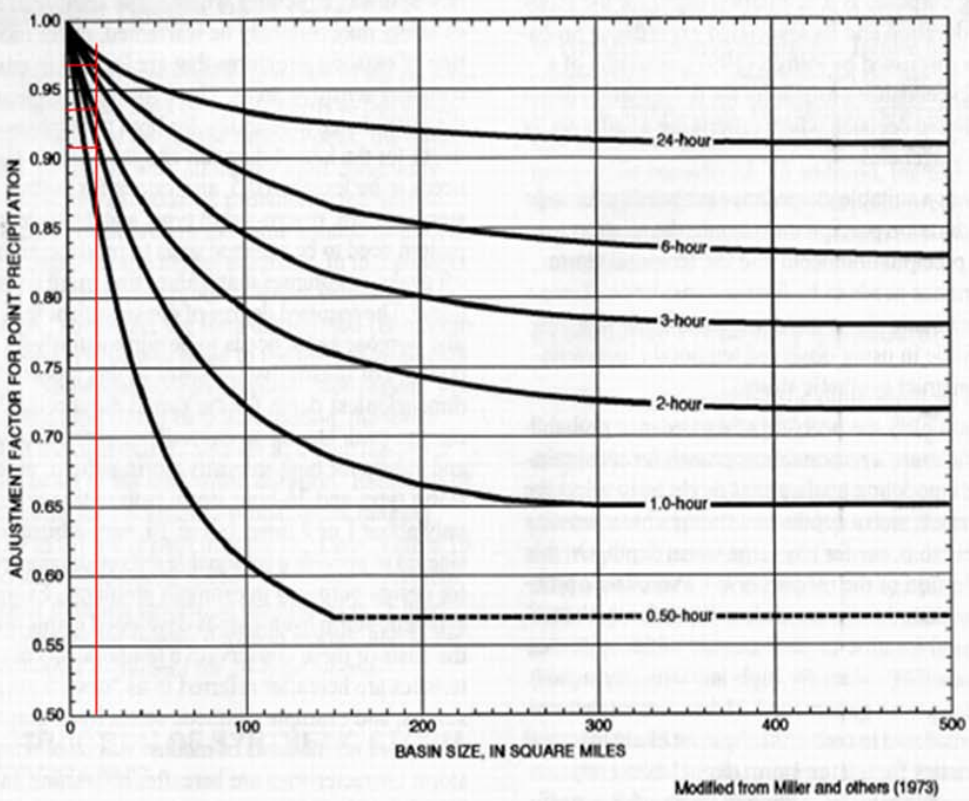


Figure 17. Depth-area adjustment curves for Montana.

24 hour precipitation hyetograph; 6 hour kernal, 50% exceedance probability for region 2 (USGS WRI 98-4100)
For 500 year storm

Fish Creek

	5.55	areal adjusted
Basin average depth	**5.67**	no areal adjustment

Use unadjusted at-site storm depth for 500 yr storm

Incremental Duration	Dimensionless depth (Table 14)	Depth-area adjustment (Figure 17)	Adjusted dimensionless depth
0	0.000	0	0
1	0.121	0.92	0.11132
2	0.197	0.938	0.184786
3	0.250	0.96	0.24
6	0.403	0.97	0.39091
9	0.556	0.972	0.540432
12	0.677	0.974	0.659398
18	0.866	0.976	0.845216
24	1.000	0.98	0.98
36	1.111	0.985	1.094335
48	1.177	0.99	1.16523
60	1.220	0.995	1.2139
72	1.238	1	1.238

Incremental Time	Incrementa dimensionless depth	Dimensionless depth per 1 hour period	Depth per 1 hour period	Incremental depth
1	0.11132	0.1113	**0.631**	**0.631**
1	0.073466	0.0735	**0.417**	**0.417**
1	0.055214	0.0552	**0.313**	**0.313**
3	0.15091	0.0503	**0.285**	**0.856**
3	0.149522	0.0498	**0.283**	**0.848**
3	0.118966	0.0397	**0.225**	**0.675**
6	0.185818	0.0310	**0.176**	**1.054**
6	0.134784	0.0225	**0.127**	**0.764**
12	0.114335	0.0095	**0.054**	**0.648**
12	0.070895	0.0059	**0.033**	**0.402**
12	0.04867	0.0041	**0.023**	**0.276**
12	0.0241	0.0020	**0.011**	**0.137**
			72 hr sum	7.019
			24 hr sum	5.557

Check - Areal adjusted precip from WRI 97-4004 should match 24 hr sum.

4. Next, distribute the incremental depths over the entire 72 hour period: a) Determine the time to peak using table 19. For a 24 hour storm in region 2 with a 50% exceedance probability, the time to peak is 27 hours. B) Distribute incremental depths using a median value hyetograph pattern.

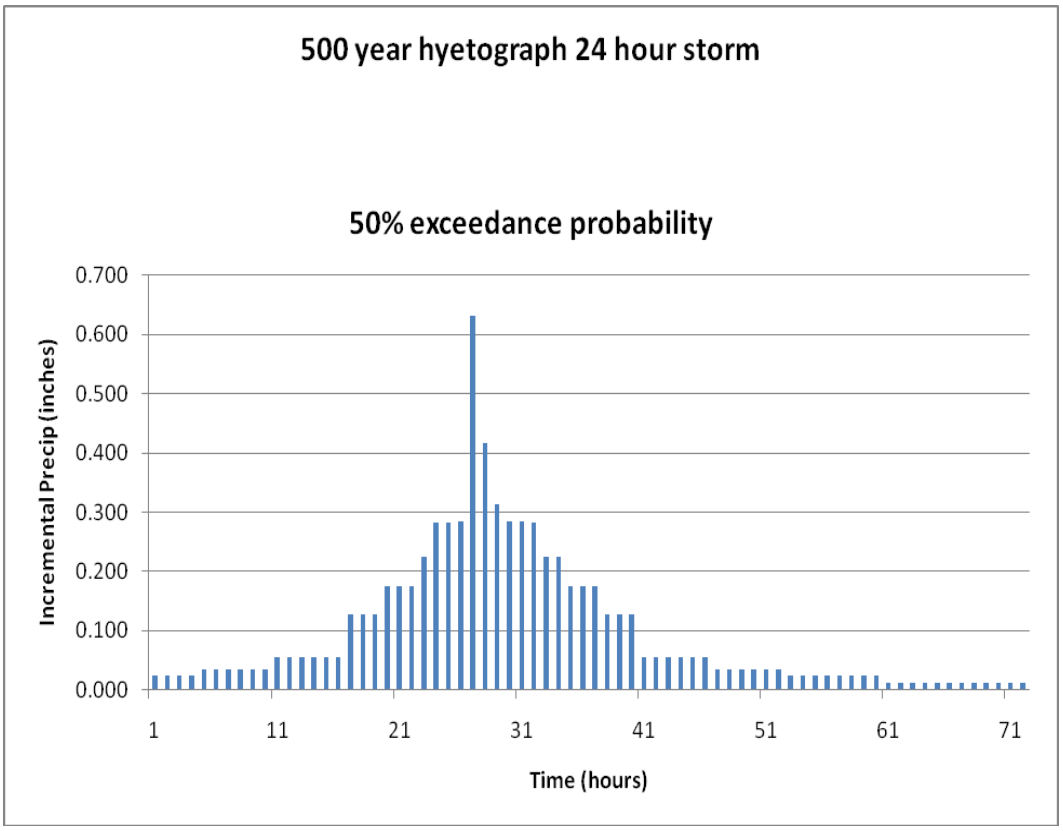
Table 19. Time-to-peak precipitation for various exceedance probabilities, Montana and northern Wyoming

Exceedance probability	Time-to-peak precipitation, in hours, for indicated independent duration, in hours, and region								
	2			6			24		
	Region			Region			Region		
	1	2	3	1	2	3	1	2	3
0.9	0.0833	0.0833	0.0833	0.25	2	0.25	2	8	4
.8	.0833	.0833	.167	.75	3	.75	5	13	7
.7	.0833	.0833	.25	1.25	4.25	1	8	18	12
.6	.0833	.0833	.417	2	5.25	1.5	12	22	17
.5	.167	.25	.50	3	6.5	2.25	17	27	22
.4	.25	.333	.667	4	7.5	3	24	32	28
.3	.417	.50	.917	5.5	9	4	31	37	35
.2	.75	.833	1.167	7.5	10.25	5	40	44	43
.1	1.167	1.333	1.583	10	12.25	7	52	52	53

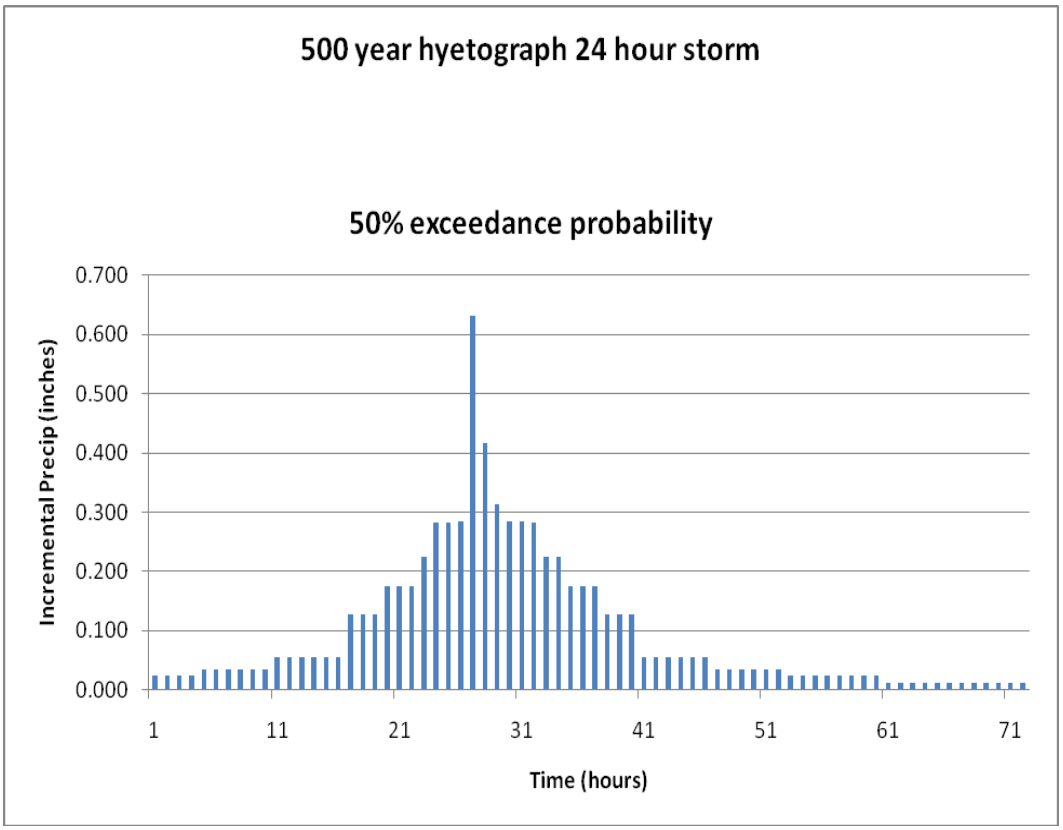
Incremental Time	Depth per 1 hour period
1a	0.631
1b	0.417
1c	0.313
3a	0.285
3b	0.283
3c	0.225
6a	0.176
6b	0.127
12a	0.054
12b	0.033
12c	0.023
12d	0.011

hour	ppc	Incr Time						
0	0.000	0						
1	0.023	12c	25	0.283	3b	49	0.033	12b
2	0.023	12c	26	0.285	3a	50	0.033	12b
3	0.023	12c	27	0.631	1a	51	0.033	12b
4	0.023	12c	28	0.417	1b	52	0.033	12b
5	0.033	12b	29	0.313	1c	53	0.023	12c
6	0.033	12b	30	0.285	3a	54	0.023	12c
7	0.033	12b	31	0.285	3a	55	0.023	12c
8	0.033	12b	32	0.283	3b	56	0.023	12c
9	0.033	12b	33	0.225	3c	57	0.023	12c
10	0.033	12b	34	0.225	3c	58	0.023	12c
11	0.054	12a	35	0.176	6a	59	0.023	12c
12	0.054	12a	36	0.176	6a	60	0.023	12c
13	0.054	12a	37	0.176	6a	61	0.011	12d
14	0.054	12a	38	0.127	6b	62	0.011	12d
15	0.054	12a	39	0.127	6b	63	0.011	12d
16	0.054	12a	40	0.127	6b	64	0.011	12d
17	0.127	6b	41	0.054	12a	65	0.011	12d
18	0.127	6b	42	0.054	12a	66	0.011	12d
19	0.127	6b	43	0.054	12a	67	0.011	12d
20	0.176	6a	44	0.054	12a	68	0.011	12d
21	0.176	6a	45	0.054	12a	69	0.011	12d
22	0.176	6a	46	0.054	12a	70	0.011	12d
23	0.225	3c	47	0.033	12b	71	0.011	12d
24	0.283	3b	48	0.033	12b	72	0.011	12d

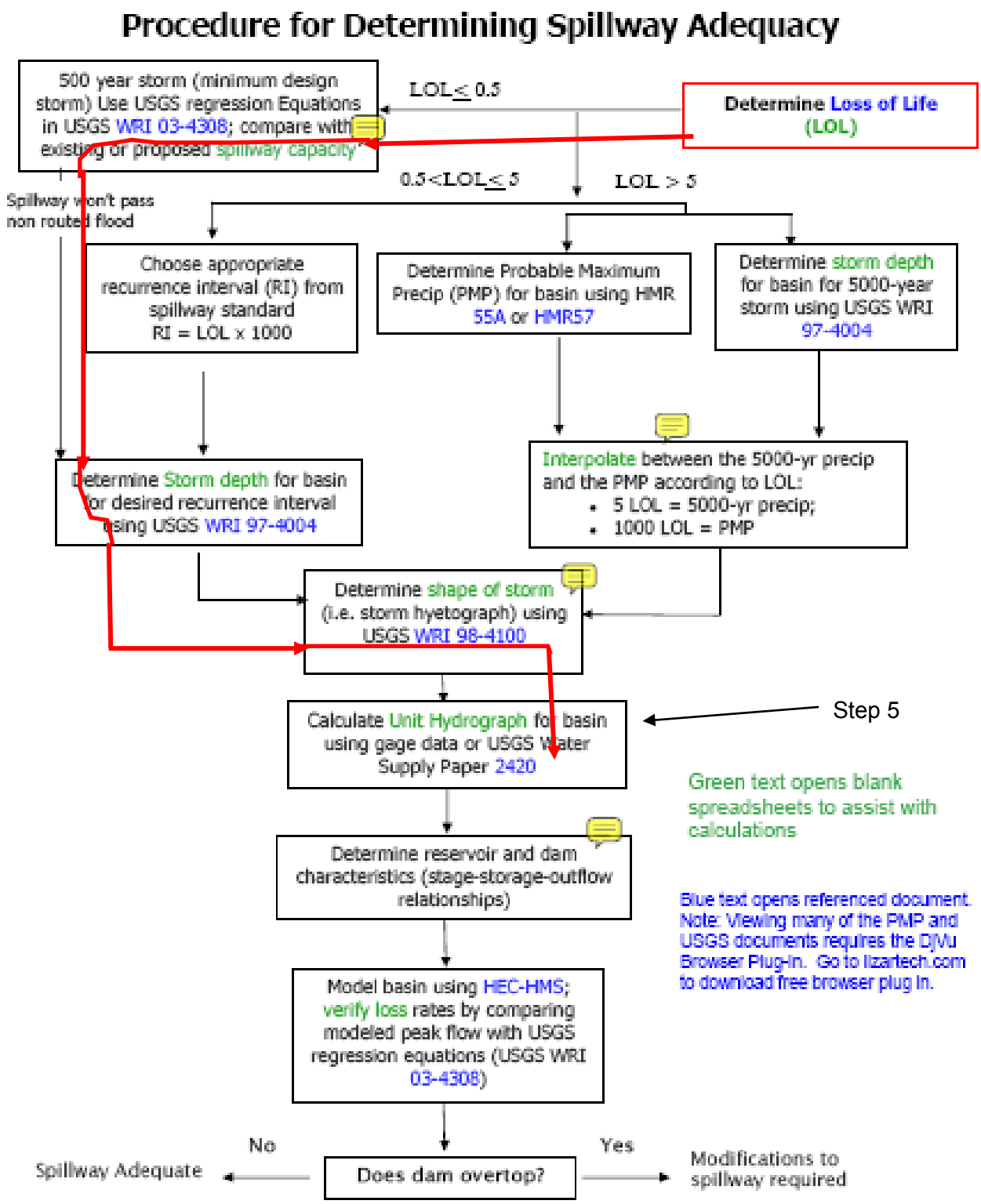
hour	ppc
0	
1	0.023
2	0.023
3	0.023
4	0.023
5	0.033
6	0.033
7	0.033
8	0.033
9	0.033
10	0.033
11	0.054
12	0.054
13	0.054
14	0.054
15	0.054
16	0.054
17	0.127
18	0.127
19	0.127
20	0.176
21	0.176
22	0.176
23	0.225
24	0.283
25	0.283
26	0.285
27	0.631
28	0.417
29	0.313
30	0.285
31	0.285
32	0.283
33	0.225
34	0.225
35	0.176
36	0.176
37	0.176
38	0.127
39	0.127
40	0.127
41	0.054
42	0.054
43	0.054
44	0.054
45	0.054
46	0.054
47	0.033
48	0.033
49	0.033
50	0.033
51	0.033
52	0.033
53	0.023
54	0.023
55	0.023
56	0.023
57	0.023
58	0.023
59	0.023
60	0.023
61	0.011
62	0.011
63	0.011
64	0.011
65	0.011
66	0.011
67	0.011
68	0.011
69	0.011
70	0.011
71	0.011
72	0.011



hour	ppc
0	
1	0.023
2	0.023
3	0.023
4	0.023
5	0.033
6	0.033
7	0.033
8	0.033
9	0.033
10	0.033
11	0.054
12	0.054
13	0.054
14	0.054
15	0.054
16	0.054
17	0.127
18	0.127
19	0.127
20	0.176
21	0.176
22	0.176
23	0.225
24	0.283
25	0.283
26	0.285
27	0.631
28	0.417
29	0.313
30	0.285
31	0.285
32	0.283
33	0.225
34	0.225
35	0.176
36	0.176
37	0.176
38	0.127
39	0.127
40	0.127
41	0.054
42	0.054
43	0.054
44	0.054
45	0.054
46	0.054
47	0.033
48	0.033
49	0.033
50	0.033
51	0.033
52	0.033
53	0.023
54	0.023
55	0.023
56	0.023
57	0.023
58	0.023
59	0.023
60	0.023
61	0.011
62	0.011
63	0.011
64	0.011
65	0.011
66	0.011
67	0.011
68	0.011
69	0.011
70	0.011
71	0.011
72	0.011



Step 5 – Determine unit hydrograph for basin



No gages are available, so a synthetic unit hydrograph must be developed using methods described in WSP 2420. The Clark synthetic unit hydrograph is used for this example.

Clark UH method

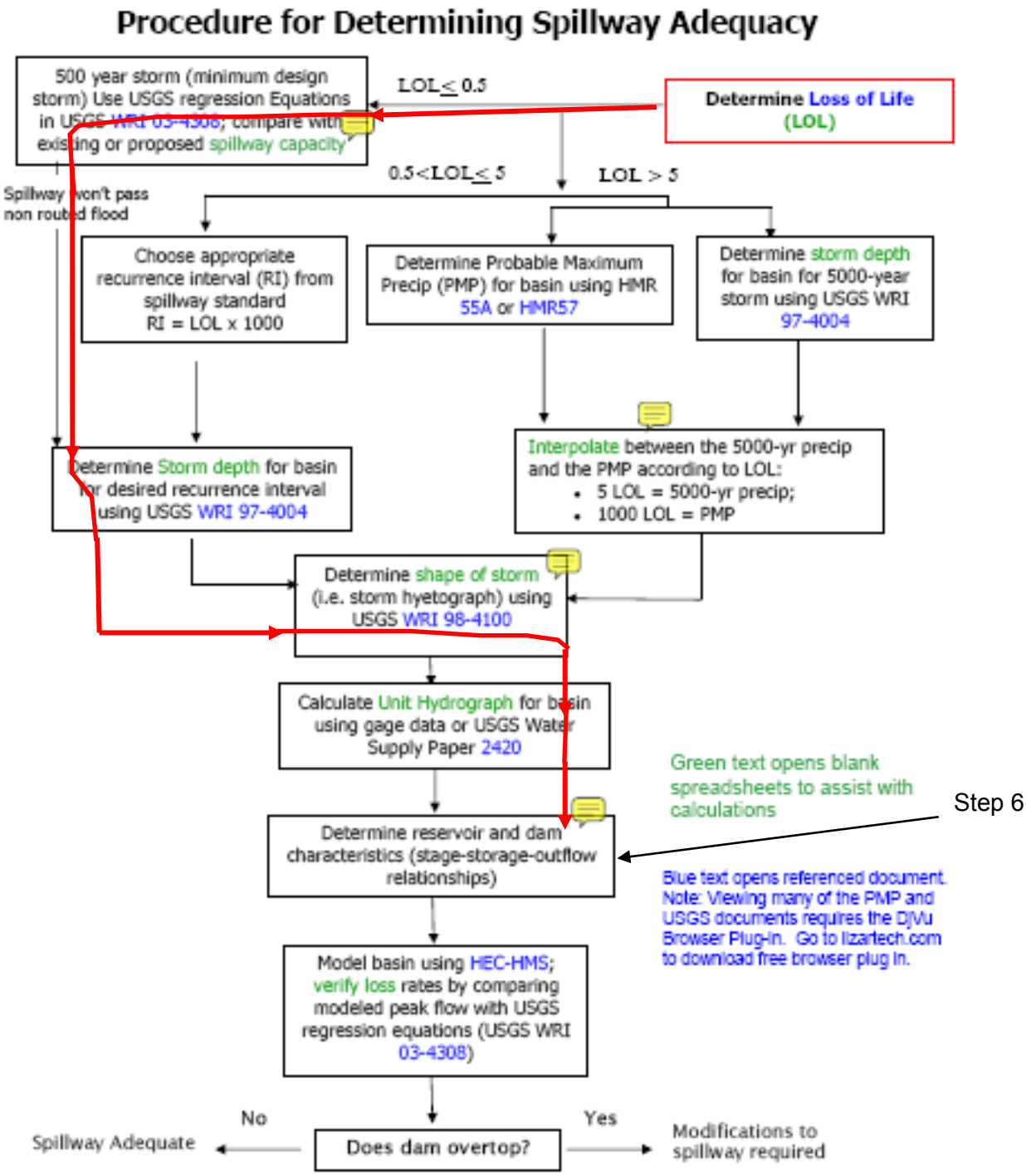
Drainage Area	Time of Concentration (hr)	Duration (hr)	Duration (min)	R Mtn sites	R plains sites
15.8	1.79	0.45	26.88	6.82	3.06

Table 4. Results of regression analysis for selected unit-hydrograph variables for stream sites in Montana

[T_c, time of concentration, in hours; A, drainage area, in square miles; R, basin-storage coefficient, in hours; t_p, Snyder standard lag, in hours; q_p, peak of dimensionless unit hydrograph; L, main channel length, in miles; L_{ca}, distance from basin centroid to mouth, in miles; S, main channel slope, in feet per mile]

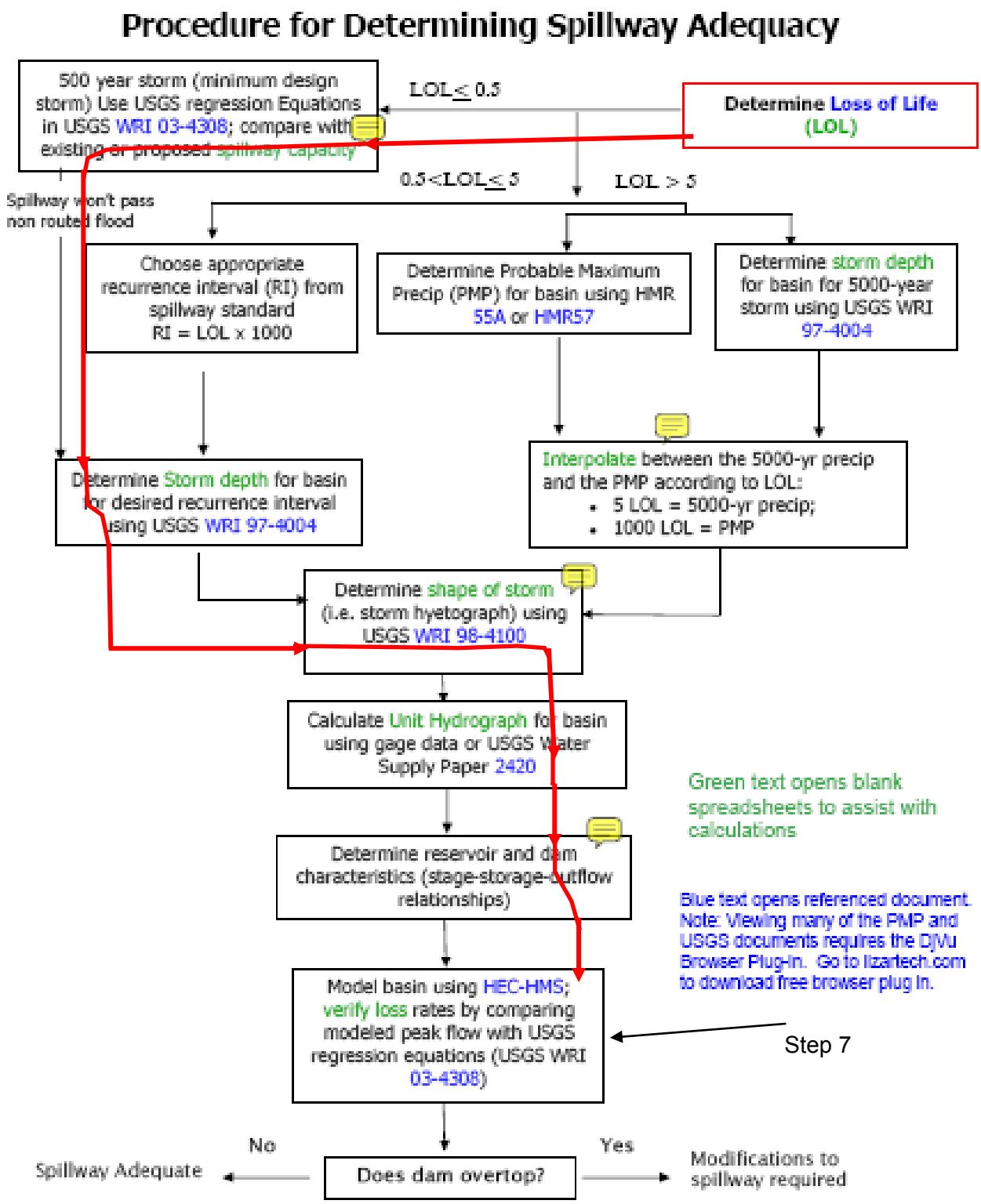
		Equation	Coefficient of determination (r^2)	Standard error (logarithm, base 10)	Equation number
T_c	=	$0.298\,A^{0.65}$	0.91	0.160	8
R	=	$2.90\,A^{0.31}$ ("mountains" sites)	.47	.390	9
R	=	$1.30\,A^{0.31}$ ("plains" sites)	.47	.390	10
t_p	=	$0.393\,A^{0.58}$	.88	.168	11
q_p	=	$8.46\,(LL_{ca}/\sqrt{S})^{0.10}$	.30	.153	12
q_p	=	$7.24\,A^{0.10}$	.19	.164	13

Step 6 – Determine stage, storage and outflow characteristics for project.



If reservoir storage cannot easily be estimated at higher pool levels above spillway crest, it may be necessary to model spillway outflow using HecHMS instead of using existing storage outflow relationships. Change spillway discharge coefficient used in HMS until spillway discharge matches existing storage outflow curve. For this example, storage outflow relationships are not available. The broad crested weir equation option in HecHMS will be used.

Step7 – Model basin using HecHMS (or other watershed model)



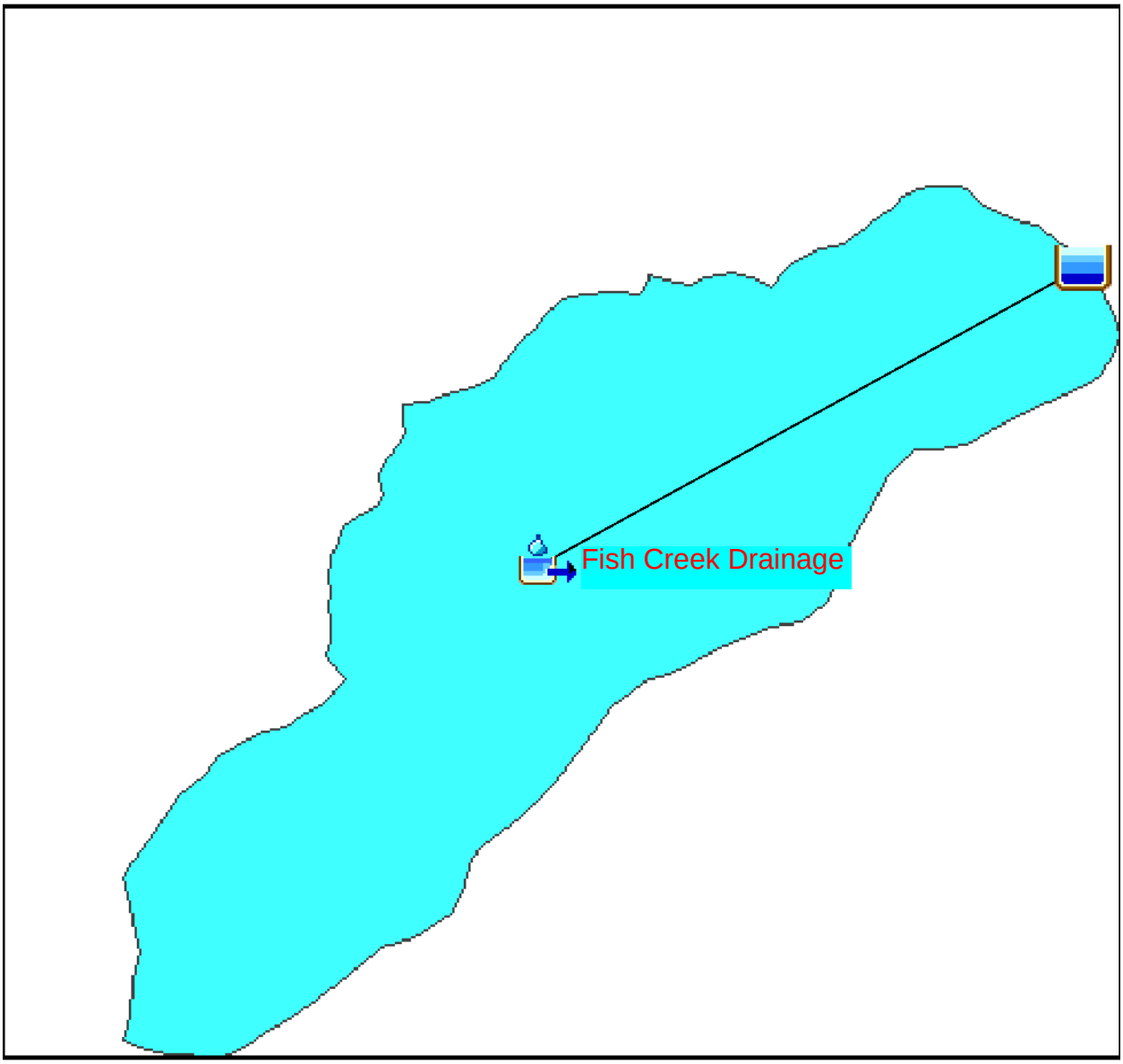
Plug your storm hyetograph, unit hydrograph, stage –storage relationships and dam information into a watershed model.

HEC-HMS

Project : Fish creek watershed

Basin Model : Fish IDF

May 10 13:24:13 MDT 2010



CN	AREA	CN X Area
0	535726.31	0.00
56	8547237.71	478645311.82
60	71847272.50	4310836350.06
70	12993482.16	909543751.16
70	51787884.46	3625151912.36
71	13413443.20	952354467.31
73	48437.40	3535930.43
75	1040354.81	78026611.08
74	1896248.36	140322378.89
72	264550464.07	19047633413.33
75	369465.09	27709882.10
77	9681.74	745493.93
77	12477393.94	960759333.23
60	975711.72	58542703.27
	440492803.49	30593807538.97

Runoff CN = 69.45

ESRI has a tool that can be used to calculate a curve number for help in determining losses using the SCS method.

Model Output at Base of Drainage Basin

Project: Fish Creek Watershed

Simulation Run: IDF 500 year storm Subbasin: fish ck drainage

Start of Run:	01Jun2008, 00:00	Basin Model: fish creek IDF	
End of Run:	06Jun2008, 00:00	Meteorologic Model:	500 yr storm
Compute Time:	10May2010, 17:17:31	Control Specifications:	Control 1

Volume Units: IN

Computed Results

Peak Discharge :	1567.4 (CFS)	Date/Time of Peak Discharge :	02Jun2008, 09:48
Total Precipitation :	6.99 (IN)	Total Direct Runoff :	3.55 (IN)
Total Loss :	3.44 (IN)	Total Baseflow :	0.06 (IN)
Total Excess :	3.55 (IN)	Discharge :	3.61 (IN)

Check output from the drainage to make sure things are reasonable:
1. Total precipitation matches 72 precipitation total from hyetograph spreadsheet. For this example, the total precipitation calculated by the model is 6.99 inches, the 72 hour sum of incremental depths from the hyetograph spreadsheet is 7.019 inches.....good match.
2. Baseflow is not dominating runoff. For this example, baseflow is about 1% of direct runoff - not a significant factor in model.
3. Peak discharge is within 25% of peak discharge calculated with USGS regression equations. If not, your losses and/or unit hydrograph parameters may need to be modified. This modification is a process called "psuedocalibration". For this example, the 500 year peak discharge calculated with USGS regression equations is 1250 cfs. The calculated peak discharge from the model barely exceeds this value by more than 25%. Options include:
Develop storms for lower frequency events using the same procedures used for developing the inflow design storm (100 year, 50 year), run the model and compare basin peak discharge to the 100 year, 50 year peak flow calculated from the USGS equations. Modify losses/UH parameters until model peak discharge better matches USGS equation peak discharge. Make sure your modifications stay within reasonable limits....The USGS Regression equations can have substantial error bounds, and should not be taken as gospel. Then rerun the inflow design storm to assess spillway performance. Before you take that step, make a few more checks.....

NOTE: In cases where the inflow design flood is greater than the 500 year storm, psuedocalibration with 50, 100, and/or 500 year storm events is always necessary, as USGS regression equations are not available for higher frequency storms.

Model Output for Reservoir

Project: Fish Creek Watershed

Simulation Run: IDF 500 year storm Reservoir: Fish Dam

Start of Run:	01Jun2008, 00:00	Basin Model: Fish IDF	
End of Run:	06Jun2008, 00:00	Meteorologic Model:	500 yr storm
Compute Time:	18May2010, 13:25:02	Control Specifications:	Control 1

Volume Units: IN

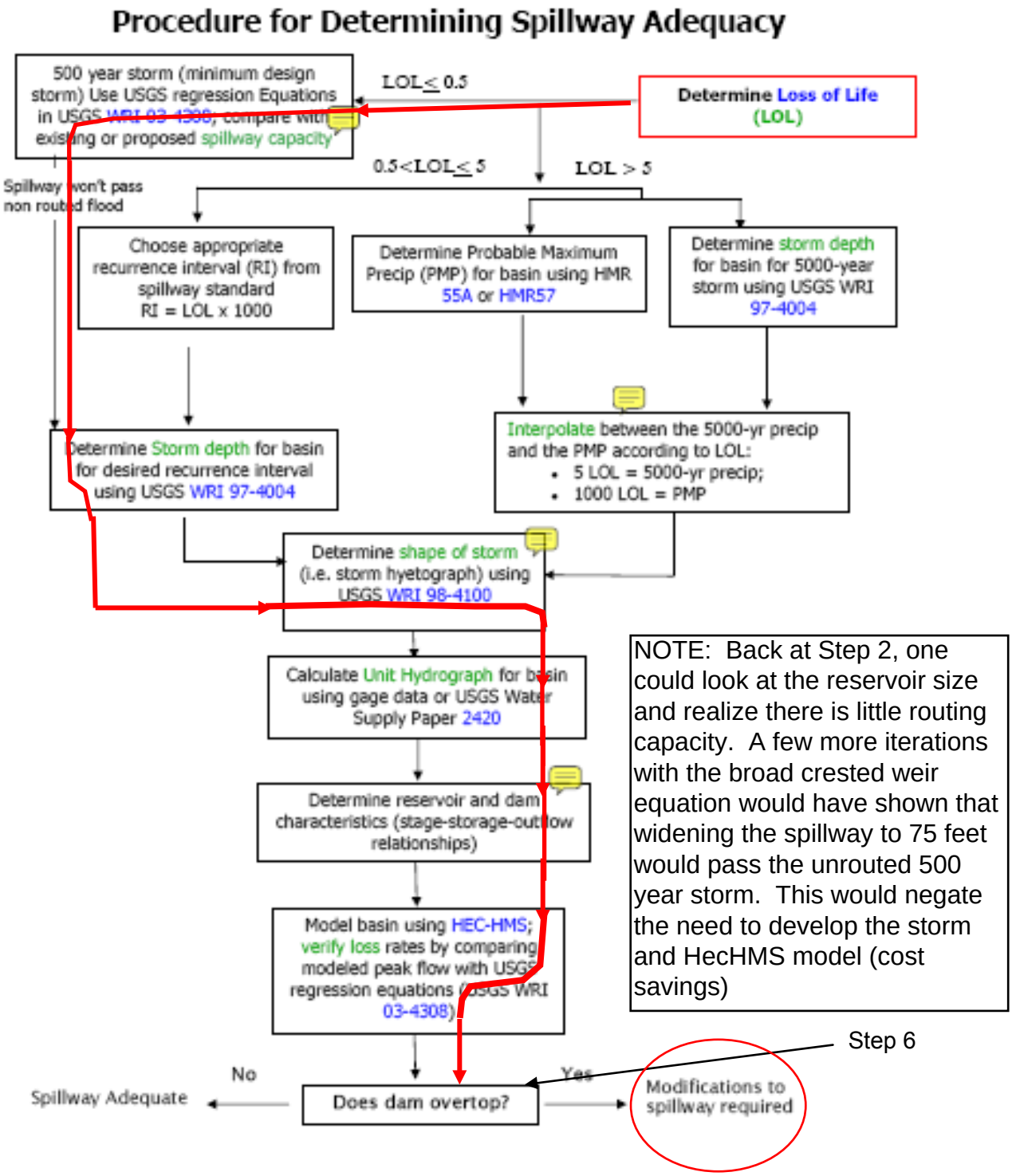
Computed Results

Peak Inflow :	1567.4 (CFS)	Date/Time of Peak Inflow :	02Jun2008, 09:48
Peak Outflow :	1566.0 (CFS)	Date/Time of Peak Outflow :	02Jun2008, 10:03
Total Inflow :	3.61 (IN)	Peak Storage :	158.7 (AC-FT)
Total Outflow :	3.61 (IN)	Peak Elevation :	4438.3 (FT)

Check output from the reservoir:

1. Compare inflow with outflow: This will give you an idea of reservoir routing capacity. For this example, the reservoir has only a small amount of routing capacity - the ability to knock the peak inflow down by 1.4 cfs.
2. Check peak elevation of reservoir: If dam is overtopped, then it may be worth going through the efforts to psuedocalibrate the model and better estimate loss rates. In this example, the dam is overtopped by 0.8 feet. Psuedocalibration may be in order. It may also be worthwhile to obtain a better estimate of stage-storage.

Step 7 – Does dam overtop?



NOTE: Back at Step 2, one could look at the reservoir size and realize there is little routing capacity. A few more iterations with the broad crested weir equation would have shown that widening the spillway to 75 feet would pass the unrouted 500 year storm. This would negate the need to develop the storm and HecHMS model (cost savings)

In this example, the dam overtops. What are your options?

1. Add fill to crest of dam (expensive - may need to modify gate controls)
2. Widen spillway
3. Refine stage storage and loss estimates in model

Note: It is a separate analysis to evaluate whether or not spillway will perform properly under high flow conditions. It is also a separate analysis to determine whether or not additional freeboard is necessary